That smells filling: effects of pairings of odours with sweetness and thickness on odour perception and expected satiety

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That smells filling: effects of pairings of odours with sweetness and thickness on odour perception and expected satiety.

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Abstract

Retronasal co-experience of odours with sweet tastes and thick textures have been shown to result in attribution of sweetness and thickness to odours when they are subsequently sniffed. Orosensory thickness and creaminess are also associated with expectations that a product will be filling. Here we test for the first time whether co-experience of odours with orosensory thickness and sweetness results in transfer of satiety expectations to these odours when subsequently sniffed. Eighty healthy volunteers evaluated the hedonic and sensory characteristics of odours, and expectations that products with the same flavour as the odour would be filling, before and after disguised co-experience of odours with sweetness (sucrose), thickness (tara gum solution) or the combination of sweet/thick, as well as untrained (control) odours. Odours paired with tara gum were subsequently rated as smelling thicker and more creamy, while odours paired with sucrose smelled sweeter. Pairing odours with tara gum increased the expectation that products predicted to have the same flavour as the sniffed odour would be more filling, and this was enhanced by sweetness, while pairing odours with tara-gum increased the expectation that products with that odour would reduce later hunger. Liking for odours paired with sweetness increased, but pairing with thickness alone reduced liking. These data suggest that satiety-consonant sensory characteristics can transfer to associated odours, and that this process is independent of changes in liking. This raises the possibility of using satiety-associated odour cues to manipulate consumer satiety expectations.

Key words

Thickness, sweet, satiety expectations, odour-taste learning.

1.0 Introduction

The experience of flavour requires multi-sensory integration of stimuli arising from the simultaneous detection of taste, smell and touch in the mouth when foods and drinks are ingested (Prescott, 2004; Small & Prescott, 2005; Spence, 2013). One consequence of the multisensory nature of flavour is that the oral co-experience of gustatory, olfactory and somatosensory stimuli can alter the way the same olfactory components are experienced when they are subsequently sniffed (i.e. experienced orthonasally). Thus, some of the apparent sensory characteristics of food-related odours (such as perceived sweetness) may actually reflect prior associations between the sensed odours and other orosensory cues such as taste and texture, possibly through activation of associated flavour memory (Stevenson & Boakes, 2003). The original evidence for this phenomenon arose from a series of studies conducted by Stevenson and colleagues in the 1990's, where participants rated the characteristics of odour stimuli before and after repeated disguised pairings of the same odours experienced retronasally alongside sweet and sour tastes (Stevenson, Boakes, & Prescott, 1998; Stevenson, Boakes, & Wilson, 2000a, 2000b; Stevenson, Prescott, & Boakes, 1995). In these studies, odours that had been paired with the sweet taste of sucrose were subsequently rated as smelling sweeter, and likewise odours paired with citric acid were rated as smelling more sour. Subsequent studies in other laboratories have confirmed these findings, and extended the tastes that transfer to odours to include bitter, etc. (e.g. Yeomans, Mobini, Elliman, Walker, & Stevenson, 2006).

As well as odours acquiring taste-like percepts, two studies suggest that pairing odours with textural qualities such as viscosity can lead to the attribution of sensory characteristics such as thickness and creaminess to sniffed (orthonasally sensed) odours. The first study paired odours with low and high fat sweetened and unsweetened milk (Sundqvist, Stevenson, & Bishop, 2006), and reported greater rated odour fattiness when sniffing the odours after having co-experienced the odour retronasally in the milk samples. However, in that study the training stimulus was complex, since milk would provide a combination of taste, odour and somatosensory information. To test more specifically whether an odour could acquire somatosensory characteristics by association with a more pure somatosensory experience, a subsequent study (Stevenson & Mahmut, 2011) examined changes in odour perception after the test odours had been paired with a tasteless viscous solution (achieved using the thickening agent carboxy methylcellulose, CMC), or a sweet and thick solution (sucrose + CMC). The rated thickness of the odour which had been paired with the sweet/thick orosensory sensation increased, although pairing an odour with thickness alone did not alter subsequent odour thickness ratings. There was also a non-significant trend for increased perceived creaminess for the odours paired with thick and sweet/thick stimuli, while as would be expected the odours paired with the sweet/thick experience during training were rated as smelling sweeter when sniffed after training. Thus these two studies suggest there is some transfer of somatosensory qualities to odours when tested using the odour-taste learning paradigm.

Repeated consumption of foods and drinks can lead to learned changes in hedonic as well as sensory characteristics of the ingested product when it is encountered again. A number of learning processes underlie the change in liking in particular (see Yeomans, 2006 for review). In the present context, co-experience of novel flavour elements (including odour) with known liked or disliked components (such as a liked sweet or disliked bitter tastes) can lead to enduring transfer of the hedonic response to the novel flavour element, a form of evaluative conditioning (Dickinson & Brown, 2007; Wardle, Mitchell, & Lovibond, 2007). Thus, odours paired with sweet tastes become more liked provided the participant liked the training sweet stimulus (Yeomans, Mobini, Bertenshaw, & Gould, 2009; Yeomans et al., 2006; Yeomans, Prescott, & Gould, 2009), while liking for odours paired with disliked bitter tastes reliably decreases (Yeomans et al., 2006).

However, although liking is a key factor in food choice and intake (see Mela, Frewer, & Trijp, 2006; Yeomans, Blundell, & Lesham, 2004 for reviews), people also develop beliefs about what impact consumption of a product will have on their appetite and thirst (Brunstrom, 2011; Forde, Almiron-Roig, & Brunstrom, 2015). These expectations can influence decisions about portion size selection, and how much of a product is consumed (Brunstrom, Collingwood, & Rogers, 2010; Brunstrom & Shakeshaft, 2009; Wilkinson et al., 2012). Analysis of the key sensory and nutritional aspects of snack products that generate expectations of satiety suggests that the perception of creaminess and thickness may be key sensory features that lead to stronger expectations of how filling a product will be (expected satiation) and how well the product will subsequently suppress hunger (expected satiety: McCrickerd, Lensing, & Yeomans, 2015). These findings, based on ratings of expectations from viewing pictures of foods, are further supported by the observation that varying the viscosity of drinks, using thickening agents like tara gum, modify ratings of expected satiation and satiety, even when the perceived differences in thickness are relatively subtle (McCrickerd, Chambers, Brunstrom, & Yeomans, 2012). These creaminess satiety cues are not limited to effects of viscosity alone: altering the size of oil particles in oil-water emulsions also modify satiety expectations. In this context, rated creaminess and thickness, and expected satiation and satiety, all increase as oil droplet size decreases (Lett, Yeomans, Norton, & Norton, 2015). Critically, the expectations generated by these subtle differences in somatosensory experience may be key in determining actual satiety responses to ingested nutrients (see Chambers, McCrickerd, & Yeomans, 2015 for recent review).

Given the clear evidence that orosensory experience of thickness or creaminess can generate expected satiety, and that pairing odours with the orosensory experience of thickness can lead to attribution of creaminess to the associated odours when sniffed (Stevenson & Mahmut, 2011), an intriguing question is then whether repeated co-experience of odours with thickness leads to attribution of increased expectations that products with the thickness-associated odour will be more filling. Expectations about how satiating a product will be are likely to be learned responses (Forde et al., 2015): evaluations of expected satiety depend on familiarity with the rated food (Brunstrom, Shakeshaft, & Scott-Samuel, 2008; Irvine, Brunstrom, Gee, & Rogers, 2013) and can change in line with ingested nutrient content following repeated exposure (Wilkinson & Brunstrom, 2009; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014). Thus the idea that these expectations can be learned is reasonably well established: the idea that these expectations can transfer through orosensory associations alone without ingestion is however untested, and was the primary purpose of the study reported here.

In the present study, participants evaluated the sensory and hedonic characteristics of target odours, as well as ratings of expectations of how filling and hunger-suppressing products with the flavour predicted by these odours would be, when the odours were sniffed. They completed these ratings both before and after a disguised training session where the same odours were experienced in the mouth paired either with sweetness alone

(Sweet: 10% sucrose), thickness alone (Thick: a tara-gum solution) or these two combined (Sweet/Thick). The basic design was thus similar to that used by Stevenson and Mahmut (2011): the critical differences were the inclusion of an odour-sweet pairing during the training phase and evaluations of expected satiation and satiety. In line with Stevenson and Mahmut (2011), we predicted an increase in creaminess and thickness ratings for odours which had been co-experienced with thickness in the mouth. We also predicted an increase in sweetness for odours co-experienced with sucrose in the mouth, in line with several earlier studies (Stevenson et al., 1998; Stevenson et al., 1995; Yeomans et al., 2006; Yeomans, Prescott, et al., 2009). Based on our finding that thickness and creaminess is associated with stronger expectations of satiety, whereas sweetness was not expected to be satiating (McCrickerd et al., 2015), we also predicted that associations with thickness would enhance the degree to which odours modified expected satiation (i.e. the immediate effects of consumption on fullness) and expected satiety (the suppression of hunger post-ingestion) based on anticipation of consuming a beverage with the thickness-associated trained odours.

2.0 Method

2.1 Study design

The study used a within-subject experimental design to contrast changes in the retronasal evaluations of three odours that had been specifically paired in the mouth with either a sweet taste (Sweet), a viscous solution (Thick) or a combination of these experiences (Sweet/Thick). Two additional odours were evaluated before and after the training session but were not experienced in the mouth, and acted as exposure controls. Since individual differences in hedonic evaluation of the three training conditions could have affected the outcome, sensory and hedonic evaluations of the Sweet, Thick and Sweet/Thick stimuli without any added odours were made after completion of the main part of the study to assess this.

2.2 Participants

Eighty healthy volunteers, 68 women and 12 men, aged 19-36 were recruited from staff and students at University of Sussex. Since the study involved tasting solutions and smelling food-related odours, potential participants who were diabetic, had an aversion to any of the test stimuli, were pregnant or breast-feeding, who smoked or were suffering from an upper respiratory tract infection were excluded. The study was advertised as 'Exploring odour and taste perception' in an email to potential participants from a database of people who had expressed an interest in participating in studies in Psychology, and the tested sample were the first 80 to respond to this email and who met the inclusion/exclusion criteria. The study protocol was approved by the Science and Technology Cross-Schools Research Ethics

Committee (C-REC) and was conducted in line with the British Psychological Society code of conduct, ethical principles and guidelines.

2.3 Materials

2.3.1 Odour stimuli

A total of 5 odours were selected for the study. Three odours were used during training where they were paired with either a sweet solution (sucrose), a thickened solution (tara gum, Kalys) or a combination of both sucrose and tara gum. The odours to be paired with these were caramel (cream caramel, Symrise, 4% solution), fig (International Flavours and Fragrances, IFF: 1% solution) and Earl Grey (IFF: 1% solution)). Two other odour stimuli were used as controls: chai (IFF: 1% solution) and almond (IFF: 1% solution). The choice of the target odours was based on a series of pilot studies, where a variety of potential odours (c. 20) were examined and rated on key dimensions of sweetness and creaminess. Past work has shown that odour-taste learning is observed most clearly where the trained odour already exhibits the trained characteristic to some degree, in line with broader sensory findings of the need for congruence between odour and taste characteristics to observe odour-induced taste enhancement (Frank & Byram, 1988; Schifferstein & Verlegh, 1996). We therefore specifically looked for odours that were rated as mildly sweet and creamy at baseline (operationalized as ratings in the range of 25-50 on visual analogue ratings of sweetness and creaminess). It was also critical that the five tested odours were easily distinguished, and again pilot studies confirmed that the selected five odours were rated low on similarity. Odour stimuli were prepared by placing 50ml of concentrated solutions of each odourant into 250ml polypropylene squeeze bottles and leaving the solution at room temperature to allow the odour to accumulate in the headspace. Stimuli were replenished at least at fortnightly intervals and allowed at least 24h to equilibrate before use.

2.3.2 Taste stimuli

For the Sweet condition, 10% sucrose was dissolved in distilled water, whereas for the Thick condition 0.2% tara gum was dissolved in distilled water as this concentration has been shown to have medium viscosity and generate clear satiety expectations (McCrickerd et al., 2012). A combination of both 10% sucrose and 0.3% tara gum in distilled water was used in the Sweet/Thick condition (note a higher tara gum concentration was required to offset the thinning effects of sucrose and achieve a similar percept of thickness to the 0.2% tara gum solution). The three taste stimuli were combined with each of the three test-odours at the following concentrations (caramel, 0.3%: fig 0.1%; earl grey 0.05%). The two control odours were combined with distilled water (chai, 0.03%; almond, 0.05%). All taste stimuli were presented in aliquots of 50ml contained in 100ml polystyrene disposable cups, which were filled on the morning of the experimental session. All solutions were refrigerated but presented at room temperature in the experimental cubicle.

2.4 Study tasks

2.4.1 Hunger evaluation

To allow for a measure of baseline hunger to be obtained, participants initially completed a set of computerised mood ratings in the form ‘How <rating descriptor> do you feel right now?’ above 100pt visual analogue scales (VAS) end-anchored with “Not at all <rating descriptor>” and “Extremely <rating descriptor>” presented using Sussex Ingestion Pattern

Monitor (SIPM 2.015) software. The key ratings were for hunger and thirst, which were mixed with distractor ratings of nervous, clearheaded, tired, happy, alert and nauseous.

2.4.2 Hedonic and sensory odour evaluations

The five bottle samples of the test odours were used to obtain sensory and hedonic ratings both before and after the orosensory training procedure. Initially, participants were briefed on how to smell the odours, which involved placing the plastic spout of the relevant squeeze bottle approximately 3cm below the nose and squeezing the bottle while sniffing. Participants were told to take as long as they wanted to smell each odour, since extra sniffing beyond the first sniff provides the participant with little further information, merely confirmation (Laing, 1983). After smelling each odour they completed VAS ratings of how creamy, intense, novel, pleasant, sweet and thick that odour smelled using 100pt VAS end-anchored with "Not at all" and "Extremely", presented using SIPM. The order of odour presentation was randomised.

2.4.3 Satiety and thirst expectations

Participants also rated their expectations of how full and thirsty they would feel after consuming a drink with the flavour of each odour and how hungry and thirsty they would feel one hour after drinking a drink with the flavour of each odour, based on methods from other studies in this laboratory (McCrickerd et al., 2015; Yeomans et al., 2014). Here, participants were provided with a portion size reference bottle containing 300ml of water with a light blue colouring as a reference, and asked to ''Imagine you have just consumed all of the drink in the bottle and that it has the same flavour as the odour you are currently smelling', followed by a series of four expectation ratings in randomized order: ''How full would you feel immediately afterwards?'', ''How hungry would you feel in 1 hour?'', 'How thirsty would you feel immediately afterwards?'' and ''How thirsty would you feel in 1 hour?''. Ratings were on a 100 point VAS scale, with end anchors ''Not at all'' and ''Extremely'' (100). These ratings were completed using SIPM immediately after the hedonic and sensory ratings for each odour.

2.4.4 Odour-taste association training.

The odour-taste training method utilised the false triangle test first used in this context by Stevenson and colleagues (Stevenson et al., 1998; Stevenson et al., 2000b; Stevenson et al., 1995), and subsequently used successfully in this laboratory (Yeomans & Mobini, 2006; Yeomans, Mobini, et al., 2009; Yeomans et al., 2006; Yeomans, Prescott, et al., 2009). To further disguise the odour-taste pairings, the task was described as a test of taste discrimination. For this task, participants were provided with five sets of three cups of solutions, three of which were training sets and two controls. On each trial, participants were asked to select one of these five sets, and to taste all three solutions using a taste-and-spit procedure. They were instructed to try and identify which of the three stimuli was the odd-one-out, and that some trials would be very difficult and some easy. If they were unsure on any trial they were asked to guess and then move to the next trial. Critically, for the three training sets, all three stimuli were the same to encourage the participant to pay extra attention to these stimuli. Of these three sets of stimuli, one set had one of the three training odours paired with the sucrose solution, one with the thickener alone and the third with the combined sweet/thick solution. The pairing of the three target odours with the three training stimuli was counterbalanced across participants. The two remaining sets of stimuli were controls and had an obvious odd-one-out in order to make the task convincing:

either water, water and almond flavour or chai, chai and water. The sequence of testing was controlled by on-screen instructions which randomised the order in which the five sets were evaluated. Participants indicated on-screen which one of the three solutions they perceived as the odd-one-out. Participants were then instructed to rinse their mouths with water, with a 10 second delay before the next trial. Participants completed a total of 4 blocks of these 5 trials, so that they experienced 12 pairings of each of the three test odours with each of the three training stimuli. The software controlling the procedure was programmed using E-Prime 1.2 (Psychology Software).

2.4.5 Responses to the trained taste stimuli

Participants completed an additional set of ratings to determine their experience of the three trained stimuli (Sweet, Thick and Sweet/Thick). The original intention was for these evaluations to be made 5 minutes after the final odour evaluation, but a programming error meant these data were not lost at that time for the first 32 participants. These ratings were either made 5 minutes after completion of the final odour evaluations for the subsequent 48 participants, and those where this data were missing were recontacted and 17 of these completed these ratings at a later date under the same test conditions as the original testing, but these data were missing for 15 participants. Participants were presented with two samples each of the three trained stimuli without any added odours, and rated their perception of thickness, creaminess, sweetness and liking for each stimulus. Ratings were again computerised VAS: the sensory ratings were in the same format as that for the odour stimuli, but for liking the end anchors were modified to read “Dislike extremely” and “Like extremely” to better capture responses of participants who were sweet likers and dislikers.

2.5 Procedure

The summary procedure is detailed in Figure 1 for clarity. Participants were asked to refrain from eating and to drink only water for 2 hours prior to the experimental session, and all testing was completed between 1000 and 1200h in a small windowless air-conditioned cubicle at the Sussex Ingestive Behaviour Unit at University of Sussex, and the procedure took around 60 minutes. On arrival, participants were provided with an information sheet which detailed the exclusion criteria and precautions, reminded them that all data would be anonymised through the use of a participant ID number and that they had the right to withdraw from the study at any time. The information sheet described the study aims as "To explore experience of food-related tastes and smells and how they relate to appetite." to draw attention from the specific odour-taste training. Testing began with completion of the mood and appetite ratings, detailed above, in order to obtain a measure of hunger since individual differences in hunger could have influenced measures of expected satiety. Participants then completed a pre-training set of evaluations of the hedonic and sensory characteristics of the five odours, and their expectations of how satiating these would be, following the procedures described above. The odour-taste training started immediately after these initial evaluations, and the post-training odour evaluations were made immediately after completion of this training. The evaluations of the training stimuli without added odours were made either 5 minutes after training ended or at a later time as described above.

Once all ratings had been completed, participants age, height and weight were recorded, they were fully debriefed on the studies true aims and they were asked if they would like their name included in a prize draw with £25 prize as a reward for their participation.

2.5 Data analysis

The key focus was on changes in odour evaluations after the training session. To ensure these changes were not generated by spurious differences in rating at the pre-training session, initial analysis of the key pre-training ratings (pleasant, creamy, thick, sweet and the four expectation measures) were contrasted using one-way ANOVA. Since the five odours consisted of three training stimuli and two unexposed controls, ratings for the two control odours were averaged, giving four test conditions (Unpaired, Thick, Sweet, Sweet/Thick). These analyses found no significant differences between conditions for any baseline expectation or sensory measure, although baseline liking in the Unpaired condition was significantly lower than in the three training conditions (Table 1). To assess effects of training, the pre-training evaluations were subtracted from those at post-training to give change scores for each measure. Changes in sensory (thick, creamy, sweet, intense, novel), hedonic (pleasant) and expectations (expected satiation and satiety) data were then contrasted between condition (Unpaired, Thick, Sweet, Sweet/Thick) using one-way ANOVA. Planned contrasts were then conducted where there were specific hypotheses, with Bonferroni corrections for multiple contrasts. Since past research suggested that hunger at the time of testing could have influenced evaluations of odours paired with sweet tastes (Yeomans & Mobini, 2006), initial hunger ratings were included as covariate in additional analyses but was found to be non-significant in all cases and was therefore omitted from the final analyses. Finally, the ratings of the training sweet, thick and sweet/thick stimuli were assessed using two-way ANOVA with training condition (Sweet, Thick and Sweet/Thick) and sample (first or second sample of each stimulus) as factors. Reported data are mean ± SEM: all analyses were conducted using SPSS 22 for Macintosh.

3.0 Results

3.1 Changes in sensory evaluations.

The key question was the extent to which pairing an odour with a sweet taste or thick texture would result in increased perception of related sensory experience when the odour was subsequently sniffed. There was no significant change in any evaluation of the untrained odours. In contrast, pairing odours with both the sweet taste and thick texture altered significantly the sensory experience of the odours after training. Changes in the rated sweetness of odours varied with condition ($F(3,237) = 2.80$, $p = 0.04$, $\eta^2 = 0.03$), with sweetness increasing in the Sweet and Sweet/Thick conditions only (Figure 2A). Changes in odour thickness also differed between conditions ($F(3,237) = 5.65$, $p < 0.001$, $\eta^2 = 0.07$): thickness increased significantly more in the Sweet/Thick than Sweet or Unpaired conditions, with Thick alone intermediate (Figure 2B). The significant differences in changes in odour creaminess ($F(3,237) = 6.17$, $p < 0.001$, $\eta^2 = 0.07$) arose from similar increases in creaminess in the Thick and Sweet/Thick conditions, but little change in the Unpaired or Sweet conditions (Figure 2C). In contrast, overall odour intensity was unaffected by training ($F(3,237) =0.34$, $p = 0.80$, $\eta^2 = 0.01$: Figure 2D).

In addition, we examined changes in odour pleasantness and novelty after training. Pleasantness varied significantly with training condition ($F(3,237) = 5.59$, $p < 0.001$, $\eta^2 = 0.07$, Table 2). Pleasantness increased slightly, but significantly more, in the Sweet and Sweet/Thick conditions, than Unexposed and Thick conditions, where liking decreased overall. For novelty, the prediction was that the three exposed odours (i.e. those in the training conditions) would become more familiar whereas this would be less so for the untrained odours which were only experienced twice, however there was no overall significant difference between conditions in changes in novelty ($F(3,237) = 1.74$, $p = 0.16$, $\eta^2 = 0.02$), although novelty tended to decrease more in the three training conditions as predicted (Table 2).

3.2 Changes in expected satiety

Changes in expectations for how full participants would expect to feel if they consumed a 300ml drink with each trained flavour (expected satiation) differed significantly between conditions ($F(3,237) = 5.53$, $p < 0.001$, $\eta^2 = 0.07$). As can be seen (Figure 3A), the largest increase in expected satiation was when rating the odour that had been paired with the combination of sweetness and thickness, which was significantly greater than the minimal changes in the Sweet and Unexposed conditions, with the increase in the Thick condition intermediate. Changes in ratings of how full they expected to feel one hour later (expected satiety: Figure 3B) also varied significantly between training conditions ($F(3,237) = 5.09$, $p = 0.002$, $\eta^2 = 0.06$), with similar increases in the Thick and Sweet/Thick conditions, both significantly greater than in the Sweet and Unexposed conditions. There were no significant effects of odour-taste training on either expectation rating for changes in thirst (data not shown for brevity).

3.3 Evaluations of the trained taste stimulus.

Fifteen participants failed to complete the evaluations of the training stimuli, and so reported data are for the 65 participants. As can be seen (Table 3), the trained stimuli had the predicted sensory characteristics: the Thick and Sweet/Thick were rated as similar in creaminess and thickness, and both significantly more thick and creamy than was the Sweet stimulus (main effect of training stimulus: thick, $F(2,128) = 256.16$, $p<0.001$, $\eta^2 = 0.80$, creamy, $F(2,128) = 147.30$, $p<0.001$, $\eta^2 = 0.70$, see Table 3 for contrasts). Likewise, the Sweet and Sweet/Thick stimuli with added sugar were rated as equally sweet, and both significantly more sweet than the unsweetened thick stimulus ($F(2,128) = 1039.58$, $p<0.001$, $\eta^2 = 0.94$). Liking also differed between the three training stimuli ($F(2,128) = 27.25$, $p<0.001$, $\eta^2 = 0.30$): the sweet stimulus was liked most, and slightly but significantly more so than the sweet/thick solution, whereas the thickened solution was moderately disliked (Table 3). There was no significant differences in any rating between the two samples of each stimulus.

In line with earlier studies (Yeomans et al., 2006; Yeomans, Tepper, Rietschel, & Prescott, 2007), changes in liking for the sweet-paired odour were positively correlated with averaged liking for the trained sweet stimulus ($r(65) = 0.47$, $p<0.001$) and the combined sweet/thick stimulus ($r(65) = 0.27$, $p =0.03$).

3.4 Responses in debriefing

When asked what the purpose of the study was, all participants responded with some variation on the description on the information sheet that the study examined how tastes and smells related to appetite, and no participant specifically commented on any connection between the odour evaluations and the taste discrimination test (i.e. the odour-taste training).

4.0 Discussion

The key findings from this first investigation of how satiety expectations generated by experience of orosensory thick and creamy sensations may transfer to sniffed odours as a consequence of the multi-sensory integration process underlying flavour perception were remarkably clear. Odours paired with the thick/creamy sensation experienced when "tasting" a tara gum solution were subsequently rated as smelling thicker and more creamy, while orosensory co-experience of odours with the sweet taste of 10% sucrose reliably increased subsequent odour sweetness. These findings replicate and extend earlier findings. The novel finding was that odours that had been paired with a thick/creamy sensation in the mouth increased both expected satiation and expected satiety, the first evidence of orosensory transfer of satiety expectations.

Orosensory coexperience of an odour with the moderately thick tasteless sensation generated by a weak tara gum solution clearly resulted in subsequent attribution of satiety expectations to the odour when sniffed. Thus imagining the effects of consuming a drink which had the same flavour as an odour that had been paired with tara gum resulted in increased expectations of feeling full after consumption and less hungry one hour later. The same changes in expectation were not seen for odours co-experienced with sweetness alone, although the combination of Sweet/Thick did resulted in a larger increased in expected satiation than did thickness alone (Figure 2A), although increased expected satiety was similar in the Thick and Sweet/Thick conditions. Given that both creaminess and thickness, but not sweetness, were associated with satiety expectations across a wide range of snack foods and drinks (McCrickerd et al., 2015), and texture but not sweetness predicted expected satiety for dairy products (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011), it appears that sweetness is not generally associated with expectations that a product will be filling, although it may be that past experience of stimuli that were thick and sweet (e.g. desserts etc.) underlies the enhanced expected satiation seen in the Sweet/Thick condition. That odours alone can acquire these expectations has potential value for product developers since the addition of relevant sensory cues (thicker texture, creamy flavour note) may increase expected satiety which in turn should increase actual nutrient-induced satiety (Chambers et al., 2015).

The evaluation of expected satiety in the present study relied entirely on rated data, in contrast to the use of more psychophysical methods based on matching portion sizes seen in other studies (e.g. Brunstrom & Rogers, 2009; Brunstrom et al., 2008; Forde et al., 2015). Part of the reason for the use of ratings alone was the difficulty of using the picture-based matching tasks with odour stimuli, and partly because our recent study found that rated satiety changed with experience more so than did expected satiety measured using portion matching (Yeomans et al., 2014). Future studies might investigate acquired expected satiety for odours using the more psychophysical approach developed by Brunstrom and colleagues to extend the current findings further.

Although the present study found evidence of increased satiety expectations for odours that had been paired with an orosensory thick texture, how these altered expectations might modify ingestive behaviour if products which included the thick-trained odours were included as part of the products flavour is unknown. Since there is clear evidence that greater expectations that a product will be filling can enhance actual satiety (both in terms of increased feelings of fullness and decreased subsequent intake: (McCrickerd, Chambers,

& Yeomans, 2014; Yeomans & Chambers, 2011)), it might be predicted that the presence of odours which generate an expectation that a product will be more filling could also act to enhance satiety. A highly controlled study using carefully controlled release of odours during ingestion has shown enhanced satiation (Ruijschop, Boelrijk, de Ru, de Graaf, & Westerterp-Plantenga, 2008), although no specific measure of satiety expectations generated by the odour used in that study (strawberry), or in subsequent studies by that group (Ruijschop, Boelrijk, Burgering, de Graaf, & Westerterp-Plantenga, 2009), was made making it hard to connect the effect of increasing odour intensity and any consequent impact of satiety expectations. Other studies report minimal effects on ingestion of altering odour release during ingestion (Ramaekers et al., 2014), but again the odours used were not specifically chosen to enhance expected satiety. There is thus a need for additional studies that first pre-condition satiety expectations in the manner reported here and then explore how the presence of these satiety-enhanced odours modify actual behaviour. A second key question is the extent to which the acquired satiety expectations would be maintained following repeated exposure. A surprising feature of the sensory changes to odours by pairing with tastes is that these acquired changes appear to be resistant to extinction (Stevenson et al., 2000b): thus the increased sweetness of a sniffed odour arising from co-experience of that odour with a sweet taste was maintained over multiple exposures post-training. The effects of repeated consumption on satiety expectations, in contrast, have only been explored under circumstances where the nutritional consequences of ingestion have the potential to modify these expectations in line with actual effects of ingestion on motivation. The outcome of such studies has been varied: some studies report changes in satiety-related expectations so that they better reflect actual nutrient content of the ingested food (Wilkinson & Brunstrom, 2009; Yeomans et al., 2014), but others report no effects of repeated consumption (Hogenkamp, Mars, Stafleu, & de Graaf, 2012). Given these varied outcomes, it is not possible to make clear predictions of how expectations based on sniffing alone would change following repeated consumption, although theoretically the prediction would be that they expectations come to reflect actual nutrient content provided that the odour cue was a reliable predictive cue.

It is also interesting to speculate why textural qualities such as thickness and creaminess generate expectations of satiety whereas taste cues typically do not (Bertenshaw, Lluch, & Yeomans, 2013; Hogenkamp et al., 2011): for example, creaminess and actual energy content reliably predicted both expected satiety and expected satiation for a range of snack and drink products, but taste qualities such as sweetness did not (McCrickerd et al., 2015). The current view (e.g. Brunstrom, 2011) is that textural cues generate expectations of satiety based on past experience where these sensations typically predict actual post-ingestive satiety: textural-based satiety expectations are a reflection of past learning. That such expectations can transfer to other cues that in turn predict texture would be consistent with second-order conditioning effects.

The sensory changes reported here largely replicated earlier findings: the increased sweetness of sniffed odours that have been paired with sweet tastes in the mouth seems especially reliable (Stevenson et al., 1998; Stevenson et al., 2000b; Stevenson et al., 1995; Yeomans et al., 2006; Yeomans, Prescott, et al., 2009). The changes in thickness and creaminess we report here however go further than the results of earlier studies (Stevenson & Mahmut, 2011; Sundqvist et al., 2006). Notably, Stevenson and Mahmut (2011) only found increased odour thickness for odours paired with a combined thick/sweet orosensory experience (their CMC + sucrose condition) and only found a trend for increased odour creaminess. Here, both thickness and creaminess ratings of odours paired with the tara gum solution in the mouth increased, although rated thickness tended to increase more in our Sweet/Thick condition. Part of the difference could be study power: noting that Stevenson and Mahmut (2011) only found a trend for increased odour creaminess, we increased the study power relative to their study. They also did not include a sweet-only training condition and that may have helped participants discriminate effects of thickness and sweetness in the present context. The over-riding evidence is that these subtle somatosensory sensations can transfer to odour perception

Alongside changes in expected satiety and perceptual characteristics, pairing odours with orosensory thickness and sweetness also altered subsequent odour pleasantness. The overall increase in pleasantness of odours paired with sweet tastes was small, but there was no attempt to pre-select sweet likers in this study, whereas past studies clearly show that actual liking for the trained sweet solution is critical in determining consequent changes in odour liking (Yeomans et al., 2006; Yeomans, Prescott, et al., 2009), and this was further confirmed by the clear positive correlation between liking for the trained sweet and thick/sweet stimuli and changes in odour pleasantness after training. The thick solution was clearly moderately disliked, but was not disgusting, and this dislike transferred to the associated odour.

Notably, the changes in thickness and creaminess of odours matched onto the pattern of changes in expected satiation/satiety and not to those for liking. This suggests two learning processes: an evaluative process driving liking change and a separate process driving satiety expectations, which is more likely to be based on the predictive nature of the thick/creamy experience. Future studies are needed to explore further how these two processes may interact.

Previously we reported that expression of increased liking for, but not acquired sensory characteristics of, odours paired with sweet tastes depended on hunger state at the time of testing (Yeomans & Mobini, 2006). Here we found no effects of rated hunger at the time of test on expression of liking, expectation measures or sensory changes to the odours, which at first appears to contradict our earlier findings. However, in the earlier work, appetitive state was manipulated to generate separate hungry and full groups, whereas here hunger was not the focus and analysis of the effects of hunger relied on natural variation at the time of testing. Notably hunger ratings in the present study averaged 47 ± 3 VAS units, closer to the hungry (54) than sated condition (32) in the earlier study, suggesting most participants were moderately hungry and that the range of hunger was then too narrow to detect any influence on the odour evaluations. Given that the effects of hunger on expressions of satiety expectations has not been widely tested, future studies might usefully explore this.

The reported study design had a number of limitations that could have influenced the study outcome. Firstly, training did not include a simple exposure condition where the participant experienced the same odour retronasally that they evaluated orthonasally, instead relying here on the two unexposed controls to test effects of learning. Other studies have included the exposure control, and retronasal exposure in the absence of an additional stimulus such as sweetness, bitterness or viscosity does not typically alter any evaluation of the exposed odour (Stevenson et al., 1998; Stevenson et al., 1995; Yeomans et al., 2006), with no differences in sensory experience after training between exposed and unexposed control odours. However, inclusion of that condition would have allowed an easier statistical test of the potential interaction between sweetness and viscosity in the present study. Secondly, here for simplicity and to allow better matching of odours at baseline, three odours were assigned to the training phase and two used as unexposed controls: it would have been preferable to have fully counter-balanced the five odours across the different roles in the study. It is very unlikely that this significantly altered the study outcome however since the key contrasts were between the training conditions rather than by reference to the unexposed controls. Moreover, the four conditions were well matched at baseline on all sensory and expectation measures: the lower baseline liking for the two untrained odours however does mean the contrasts between changes in liking between that condition and the three training conditions needs to be treated with caution. Finally, although we attempted to disguise the study to some extent, since we rely on self-report measures, the potential for demand effects cannot be discounted although responses in debriefing did not suggest any participant had determined the explicit study hypotheses or connected explicitly the training experience with the odour evaluations.

In summary, the present study shows for the first time that disguised co-experience of odours with orosensory thickness results in both subsequent attribution of somatosensory characteristics to these odours and critically the acquired expectation that drinks whose flavour matches the texture-associated odour will be more filling. This raises the novel idea of using subtle odour notes to direct consumer satiety expectations.

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6.0 References

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Table 1. Baseline evaluations of the four odour conditions. Data are mean ± SEM, n = 80. Cited F values are from overall one-way ANOVA for each characteristic. Where odours differed significantly, values labelled with different superscripts differ significantly ($p<0.05$ or greater).

Rated characteristic	Training condition				Overall significance
	Sweet	Thick	Sweet/Thick	Unexposed	
Creamy	36 ± 3	36 ± 3	42 ± 3	37 ± 2	$F(3,237) = 1.06$, $p=0.37$
Intense	42 ± 2	36 ± 2	36 ± 2	38 ± 2	$F(3,237) = 1.84$, $p=0.14$
Novelty	46 ± 2	49 ± 3	47 ± 2	45 ± 2	$F(3,237) = 0.60$, $p=0.61$
Pleasant	56 ± 3 [b]	57 ± 3 [b]	51 ± 3 [b]	36 ± 2 [a]	$F(3,237) = 17.83$, $p<0.001$
Sweet	46 ± 2	49 ± 3	47 ± 2	45 ± 2	$F(3,237) = 0.60$, $p=0.61$
Thick	34 ± 2	36 ± 3	34 ± 3	38 ± 2	$F(3,237) = 1.22$, $p=0.30$
Expected immediate fullness	51 ± 3	51 ± 3	50 ± 2	48 ± 2	$F(3,237) = 0.63$, $p=0.60$
Expected later hunger	49 ± 2	49 ± 3	50 ± 2	49 ± 2	$F(3,237) = 0.05$, $p=0.98$

Table 2. Changes in rated pleasantness and novelty of the odours in the four training conditions: Unpaired; Sweet (sucrose); Thick (tara gum); Sweet/Thick (sucrose + tara gum). All data are mean ± SEM, n=80: in each row, values marked by different superscripts differ significantly ($p<0.05$ or greater).

Evaluation	Training condition			
	Unpaired	Sweet	Thick	Sweet/Thick
Pleasant	-3.5 ± 2.1^{a}	4.0 ± 2.8^{b}	-8.8 ± 2.6^{a}	2.8 ± 2.8^{b}
Novel	-7.7 ± 2.5^{a}	-13.9 ± 3.0^{ab}	-17.7 ± 3.4^{ab}	-12.8 ± 3.6^{ab}

Table 3. Evaluations of rate pleasantness, sweetness, creaminess and thickness for the three training stimuli: Sweet (sucrose); Thick (tara gum); Sweet/Thick (sucrose + tara gum). All data are mean ± SEM, n=65: in each row, values marked by different superscripts differ significantly ($p<0.05$ or greater).

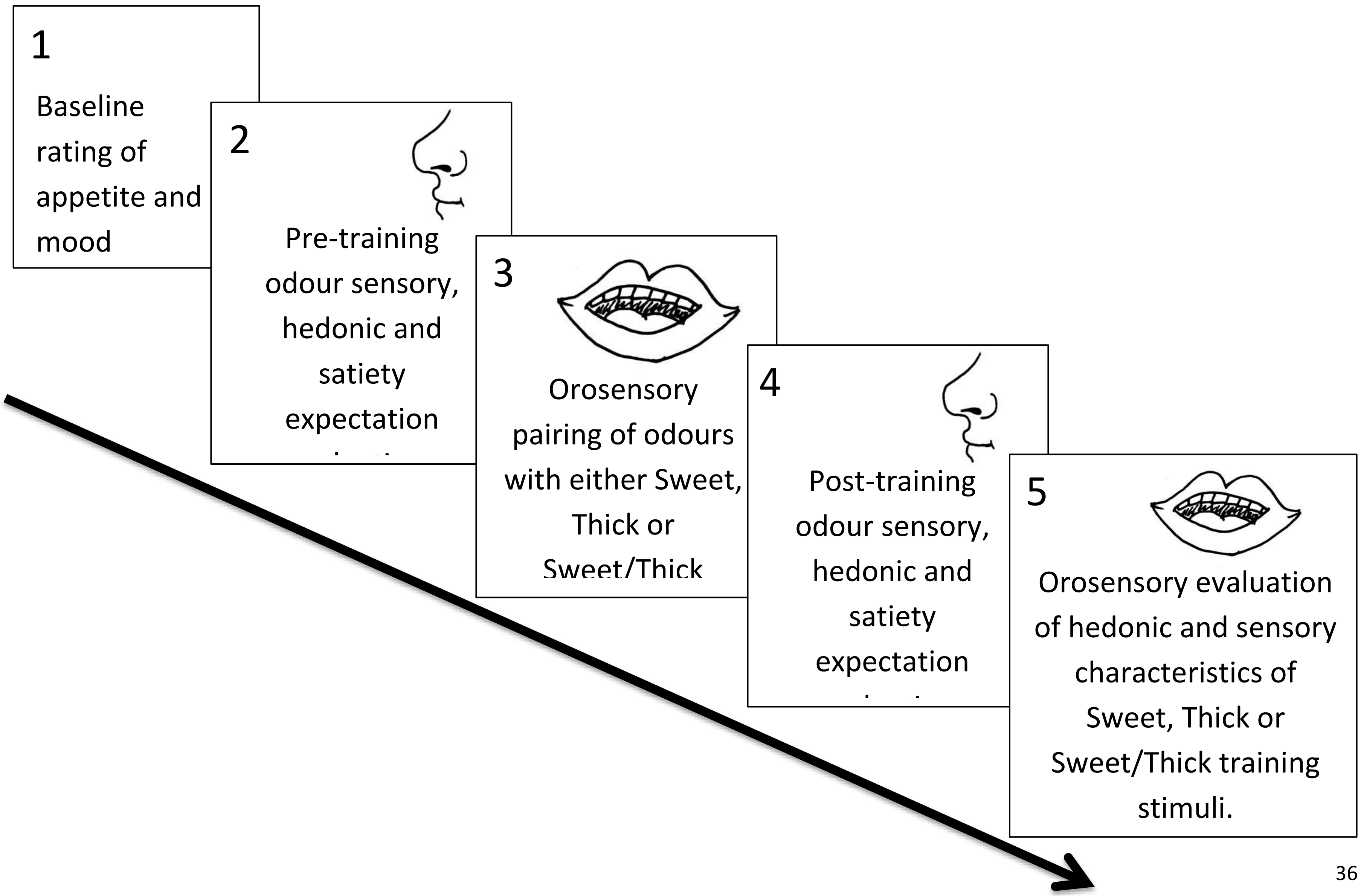
Evaluation	Training condition		
	Sweet	Thick	Sweet/Thick
Pleasant	58.2 ± 2.9^{a}	38.2 ± 1.9^{b}	51.3 ± 2.7^{a}
Sweet	78.0 ± 2.0^{a}	4.8 ± 2.7^{b}	80.2 ± 2.2^{a}
Creamy	7.6 ± 1.0^{a}	36.0 ± 2.2^{b}	39.9 ± 2.1^{b}
Thick	7.9 ± 0.9^{a}	37.3 ± 2.2^{b}	39.4 ± 2.0^{b}

Figure legends

Figure 1. Schematic summary of the study protocol.

Figure 2. Changes in the rated (A) sweetness (B) thickness (C) creaminess and (D) intensity of odours which had either been Unpaired or which had been paired in the mouth with sucrose (Sweet), a tara gum solution (Thick) or a combination of sucrose and tara gum (Sweet/Thick). All data are mean ± SEM, n=80: bars marked by different letters differ significantly ($p<0.05$ or greater).

Figure 3. Changes in rated (A) expected satiation and (B) expected satiety for odours which had either been Unpaired or which had been paired in the mouth with sucrose (Sweet), a tara gum solution (Thick) or a combination of sucrose and tara gum (Sweet/Thick). All data are mean ± SEM, n=80: bars marked by different letters differ significantly ($p<0.05$ or greater).


1
Baseline rating of appetite and mood
2
Pre-training odour sensory, hedonic and satiety expectation
3
Orosensory pairing of odours with either Sweet, Thick or Sweet/Thick
4
Post-training odour sensory, hedonic and satiety expectation
5
Orosensory evaluation of hedonic and sensory characteristics of Sweet, Thick or Sweet/Thick training stimuli.